Abundances and depletion of iron-peak elements in the Strontium Filament of Eta Carinae

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Abstract

Strontium Filament found in the ejecta of Eta Carinae. To this end we interpret the emission spectrum of neutral C and singly ionized Al, Sc, Ti, Cr, Mn, Fe, Ni, and Sr. using multilevel non-LTE models for each ion. Since the atomic data for most of these ions was previously unavailable, we carry out ab initio calculations of radiative transition rates and electron impact excitation rate coefficients. The observed spectrum is consistent with an electron density of the order of 10^7 cm^{-3} and a temperature between 6000 and 7000K. The observed spectra indicate large enhancements in the gas phase Sr/Ni, Sc/Ni, and Ti/Ni abundance ratios relative to solar values. By contrast, the abundance ratios Cr/Ni, Mn/Ni, and Fe/Ni are roughly solar.

In order to explain these results we explore various scenarios of depletion and dust destruction, in the context of nitrogen-rich chemistry. Finally, we discuss the implications of these findings for the generation of dust during the AGB phase of supermassive stars.

Introduction

The Strontium filament is in the skirt part of the Homunculus at about 1.5 arcsec to the north-east of η Carinae and moving towards the observer at -100 km/s. The filament was originally identified by [Sr II] emission lines in the red. No emission lines of H or He are present. Only weak [C I] emission is identified among the light elements, but hundreds of emission lines of neutral and singly ionized iron-peak elements are present. Despite the relative proximity to the central ionizing source, the filament is shielded from Ly α and Ly ionizing photons.

We engaged in a systematic study of the mechanism responsible for the excitation of the spectrum, the chemical composition of the spectrum, and dust formation chemistry in the filament. This works needs to begin from the determination of the atomic parameters of each species, followed by building spectral models and determination of abundances. Here we review the results of this work.

Atomic data

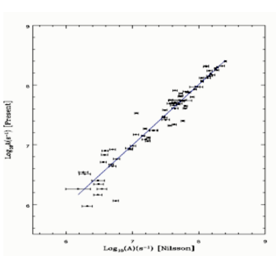

Fig. 1. Comparison of log(A) for Cr II between our calculations and experimental determinations of Nilsson et al. (2006).

	Sc	Ti	V	Cr	Mn	Fe	Co	Ni
I								
II	B08	B06		B08	B09	B05		B04
III						Z96		B01
IV						Z97		M05

B08: Bautista et al. 2008
B06: Bautista et al. 2006
B05: Bautista & Pradhan 1998; Bautista et al. 2004
Z96: Zhang 1996; Nahar & Pradhan 1996
Z97: Zhang & Pradhan 1997
B04: Bautista 2004
B01: Bautista 2001
M05: Meléndez & Bautista 2005
B09: Bautista et al. 2009
■ To be done within the present project

We have calculated atomic data (transition rates for dipole allowed and forbidden transitions and collision strengths for electron impact excitation) needed to model the spectra of Sc II, Ti II, Cr II, Mn II, Ni II, and Sr II. For this we have used state-of-the-art theoretical methods, i.e the atomic structure code AUTOSTRUCTURE for radiative data and the R-matrix methods for scattering calculations. The calculated data is compared against any other available data from either theoretical calculations or experiments.

Spectral modes

Our spectral models include electron impact excitation and continuum fluorescence, with the radiation field approximated by a black body with temperature T_R=35,000K for photon energies below the Ly limit times a dilution factor w

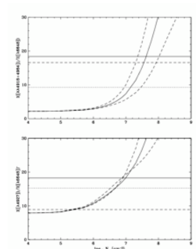

Fig. Ti II density diagnostics. The three curves correspond to T_e=6000K (solid), 5000 and 7000 (dashed). The horizontal lines depict the observed ratios from Mar 2000 (dashed), Apr 2001 (dotted), and Nov 2001 (solid).

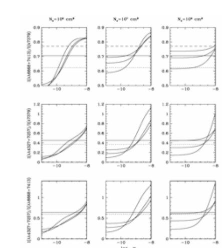

Fig. Ni II diagnostics of the dilution factor. The line ratios are computed for T_e=5000, 7000, and 9000K. The observed line ratios are depicted by horizontal lines

Diagnostics were carried out from spectra of all species available. The average conditions are T_e=6000 K, N_e=10^7 cm^{-3}, and w=10^{-9}, although there is evidence from significant spatial variations.

We estimate the relative abundances of various elements. The main uncertainty here remains in the determination of ionic fractions, which is hampered by lack of detailed modeling of the plasma.

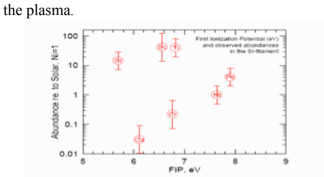

Fig. Abundances in the filament vs. first ionization potential

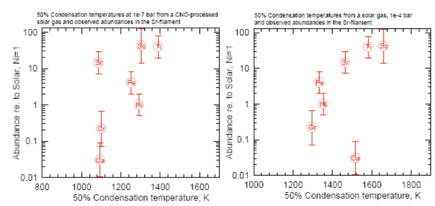

Fig. Abundances in the filament vs. condensation temperature

Non-equilibrium condensation in η Carinae

If originally all elements were in gas and condensed we would expect a behavior opposite to what is observed. Heating and evaporation of grains does not work either. We propose non-equilibrium condensation in a photoionized plasma.

As the filament is shielded from photons with energies above 8 eV, elements with equal or higher FIP (e.g. Fe, Ni) recombine and condense but elements with lower FIP (e.g. Sc, Ti, Sr) remain ionized and their condensation is delayed.

In η Car, like in all supermassive stars, the abundances of C and O are very low due to incomplete CNO processing. Thus, unlike in most well studied scenarios in condensation in η Car is driven by N. In N driven condensation non-equilibrium condensation is more likely to occur.

Conclusions and discussion

Ti and Sc are believed to be important seeds to the formation of C-based dust grains. Delaying condensation of these elements in circumstellar nebula would have important consequences on the whole dust content:

-Dust in the circumstellar nebula should be mostly made of silicates

-The dust-to-gas-ratio should be considerably lower than in galactic gas nebulae

-Likely, this effect is common to variable, massive, very bright stellar systems

-Systems of these kind were particularly important to galactic evolution in the early Universe.